Reduction of Excessive Cold Bias in GFS 2-m Temperature Forecasts in Snow-Free Seasons

Weizhong Zheng[1], Kenneth Mitchell[3], Michael Ek[2], Jack Kain[2], Helin Wei[1]

[1]IMSG at NOAA/NCEP/EMC, College Park, MD 20740, USA; [2]NOAA/NCEP/EMC, College Park, MD 20740, USA; [3]Prescient Weather Ltd, State College, PA 16803, USA
Email: Weizhong.Zheng@noaa.gov

1. Introduction

Understanding and predicting 2-m surface temperature forecasts over land in numerical models is regarded as both essential and challenging, owing to multiple related physical processes and their complex interactions. It has long been known that the Global Forecast System (GFS) of the National Centers for Environmental Prediction (NCEP) has large errors in the forecast of near-surface air temperature in some regions (e.g., Bosveld et al. 2014). In particular, excessive cold biases of 2-m air temperature are typical in the late afternoon and nighttime, especially during spring, autumn and winter, suggesting the biases are related to the transition from the daytime unstable boundary layer to nocturnal stable conditions.

Zheng et al. (2017) proposed practical approaches to reduce the excessive cooling of surface skin temperature and 2-m air temperature and prevent the collapse of turbulence and potential numerical instability resulting from thermal decoupling of the land surface and atmosphere. The most effective of the three modifications is introducing a constraint on the (*z/L*) stability parameter in the Monin-Obukhov similarity theory. Applying these modifications to the GFS surface layer parameterization (Zheng et al., 2017), this study executes daily GFS 7-day test forecasts for one month in early autumn to determine if GFS 2-m air temperature forecasts are consistently improved during a full month of daily forecasts under snow-free conditions.

2. Assessment of daily autumn forecast experiments

Unlike the winter period in Zheng et al. (2017), this early autumn period is virtually snow-free over the entire CONUS land surface (except locally over high mountains). The NCEP operational GFS forecasts presented here illustrate that the excessive GFS cooling of 2-m temperature over land in the late afternoon and nighttime also occurs in snow-free conditions. This phenomenon frequently occurs over much of CONUS as well as Alaska (though part of Alaska is covered by snow during this autumn case).

The impact of the changes on early autumn GFS 2-m temperature forecasts is similar to that in winter, but the error reduction achieved in the sensitivity experiment is less than in winter. Therefore, we examine smaller sub-regions to better see the impact of the changes. Figure 1 presents the areal and temporal mean diurnal cycle (Fig.1a) and root-mean-square error (RMSE) (Fig. 1b) of the GFS control run (CTL) and experiment (EXP) forecasts of 2-m surface air temperature over the Northwest CONUS, as a function of the model 7-day forecast length. The Northwest subregion is mostly covered in needleleaf evergreen forest with a large roughness length. The CTL exhibits some warm biases in the morning and near noon, but a rather large cold bias in the late afternoon and nighttime, approaching 3.5 ℃. The EXP significantly reduces the cold bias, up to 1.5 ℃ near sunset. The CTL RMSE typically features the largest errors in late afternoon (Fig. 1b). The RMSE reduction in the EXP is quite evident during the 7-day forecast, particularly around 0000 UTC daily, which is a transitional period from daytime unstable to nocturnal stable conditions. It is noteworthy that not only does the EXP RMSE reduction reach 1.2 ℃, which amounts to about a 25% reduction of total RMSE versus the CTL, but the daytime RMSE also dropped.

In Figure 2, forecast vertical temperature profiles verified against observed soundings reveal that CTL has a consistent warm bias in the low atmosphere. The excessive surface cooling and associated decoupling arising from the very small, or virtually zero surface sensible heat flux in very stable conditions, results in a counterpart *warm* bias in the lower atmosphere *above* the surface layer. Thus, as in winter, the impact in early autumn is more evident in the colder Northern Hemisphere than the Southern Hemisphere or Tropics. As seen in Figure 2 at the 12-h and 36-h forecast, the reduction of bias and RMSE is obvious in the EXP from the surface up to 850 hPa in the Northern Hemisphere. More notable impacts can be found in the NH sub-regions such as North America, Asia (5 °N - 65 °N and 60 °E - 145 °E) and Europe (30 °N - 70 °N and 10 °W - 45 °E). In North America where the 12-h and 36-h forecasts are in the early morning, the warm bias is reduced to about 0.25 ℃ in EXP. The EXP reduction of bias and RMSE extends from the surface up to 700 hPa, which is much deeper than the boundary layer. In Asia where the 12-hour and 36-hour forecasts are late afternoon, the CTL also has a warm bias near the surface and this warm bias is again reduced in the EXP. Moreover, in Europe where the 12-hour and 36-hour forecasts are around noon, the impact is also obvious, despite the proposed surface layer changes being oriented toward the stable boundary layer.

Last, the precipitation forecast skill in early autumn over the CONUS shows some improvement in the 12-h to 36-h forecast range or the 36-h to 60-h forecast range, but is not shown because the skill difference does not attain the 95% confidence level. Unlike in winter, precipitation in the relatively warm late summer and early autumn period of August 15 to September 22 is mainly convective, which is usually initiated during unstable daytime hours, and is much less often associated with stable boundary layer conditions. Therefore, the stable surface layer modifications proposed in this study were not expected to meaningfully impact precipitation forecast skill in late summer and early autumn.

3. Summary and ongoing research

A comprehensive set of daily 7-day GFS forecast experiments spanning one-month or longer period in early autumn demonstrated that the proposed approach considerably reduced 2-m temperature cold bias and RMSE in the late afternoon and evening. These model changes also affected levels above the surface layer and obviously reduced the bias and RMSE of atmospheric temperatures in the lower troposphere. No significant impacts are seen in warm-season precipitation forecasts over CONUS, given that the convective precipitation dominating the warm season is mostly associated with daytime unstable boundary layers.

There are still many issues related to coupled land-atmosphere processes and forecasts of near-surface fields. With the first version of FV3 dynamic core based GFS, more studies on the interactive land surface with radiation processes, PBL, clouds, etc., will be performed and further reduction of model forecast errors of near-surface fields is anticipated.

References

Bosveld, F. C., P. Baas, G. Steeneveld, A. A. M. Holtslag, W. M. Angevine, E. Bazile, E. I. F. de Bruijn, D. Deacu, J. M. Edwards, M. Ek, V. E. Larson, J. E. Pleim, M. Raschendorfer and G. Svensson, 2014: The GABLS third intercomparison case for model evaluation. Part B: SCM model intercomparison and evaluation. Bound.-Layer Meteor., 152, 157-187, doi:10.1007/s10546-014-9919-1.

Zheng, W., Ek, M., Mitchell, K., Wei, H., & Meng, J. (2017). Improving the stable surface layer in the NCEP global forecast system. Monthly Weather Review, 145, 3969– 3987, https://doi.org/10.1175/mwr-d-16-0438.1.

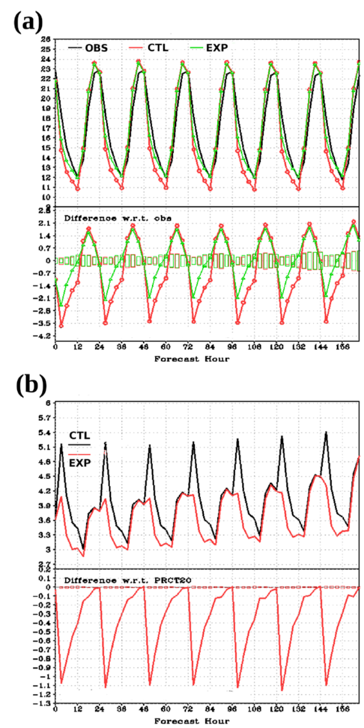

FIG. 1. (a) (top) Mean 7-day diurnal cycle of T2m (°C) averaged both spatially over the northwest CONUS and temporally over the period of 15 Aug–22 Sep 2014, for observations (black), and 7-day GFS forecast from CTL (red) and EXP (green); (bottom) as in (top), but shows difference of CTL (red) and EXP (green) from observations, plus the results of a statistical Student's t test/significance test. The differences outside of the hollow bars attain the 95% confidence level based on the Student's t tests. (b) (top) Corresponding RMSE of CTL (black) and EXP (red) with respect to observations as function of forecast length over 7 days for the same period as in (a); (bottom) difference of CTL and EXP time series in the top plot, plus the results of a statistical Student's t test/significance test. The differences outside of the hollow bars attain the 95% confidence level based on the Student's t tests.

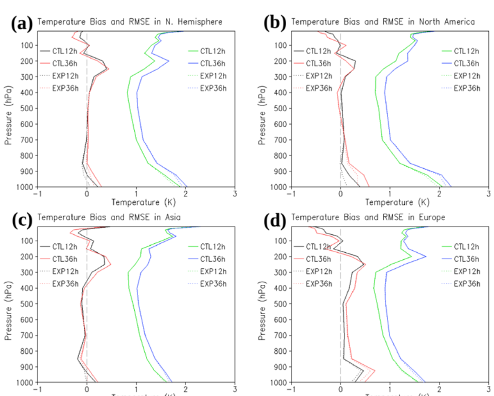

FIG. 2. Mean vertical profiles of air temperature (K) bias and RMSE for CTL (solid) and EXP (dot–dash) forecasts verified against radiosonde observations, as temporally averaged over the period of 15 Aug–22 Sep 2014 and spatially averaged over the (a) Northern Hemisphere, (b) North America, (c) Asia and (d) Europe. Black lines (red lines) are bias from 12-h (36 h) forecasts. Green lines (blue lines) are RMSE from 12-h (36 h) forecasts.